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Corrigendum to "Emission trends and mitigation options for air pollutants in East Asia" published in Atmos. Chem. Phys., 14, 6571–6603, 2014

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In Sect. 3 of this paper, some headings and their content were arranged incorrectly during typesetting. The corrected version of Sect. 3 is shown below.

3 Future emission scenarios for air pollutants

To quantify the effects of various measures on future air pollutant emissions, in this study we developed emission scenarios for SO_2, NO_x, PM, and NMVOC based on energy-saving policies and end-of-pipe control strategies. The scenarios are developed with the same model structure as that used for the estimation of historical emissions developed in our previous paper (Zhao et al., 2013c). The energy service demand is estimated based on driving forces (e.g., GDP and population). The future technology distribution and energy efficiencies are assumed and the energy consumption is calculated accordingly. Both historical and future emissions are derived from energy consumption, emission factors, and assumptions on the penetration of control technologies. For details, see Zhao et al. (2013c).

We developed two energy scenarios, a business-as-usual scenario (BAU) and an alternative policy scenario (PC). The BAU scenario is based on current regulations and implementation status (as of the end of 2010). In the PC scenario, we assume the introduction and strict enforcement of new energy-saving policies, including ones leading to a more energy-conserving lifestyle, structural adjustment, and energy efficiency improvement. Energy-conserving lifestyle is defined by a slower growth of energy service demand that would result from less building area, a smaller vehicle population, and reduced consumption of energy-intensive industrial products, electricity, and heat. Structural adjustment includes promotion of clean and renewable fuels and energy-efficient technologies. Examples include renewable energy sources and combined heat and power (CHP) for power plants and heat supply, arc furnaces and large precalciner kilns for the industrial sector, biogas stoves and heat pumps for the residential sector, and electric and biofuel vehicles for the transportation sector. Energy efficiency improvement refers to the improvement of the energy efficiencies of individual technologies.

We developed three end-of-pipe control strategies for each energy scenario, including baseline (abbreviated as [0]), progressive [1], and maximum feasible control [2], thereby constituting six emission scenarios (BAU[0], BAU[1], BAU[2], PC[0], PC[1], and PC[2]). The baseline control strategy [0] assumes that all current pollution control regulations (as of the end of 2010) and the current implementation status would be followed during 2011–2030. Control strategy [1] assumes that new pollution control policies would be released and implemented in China, representing a progressive approach towards future environmental policies. For other countries, we assume the same controls as strategy [0]. Control strategy [2] assumes that technically feasible control technologies would be fully applied by 2030, regardless of the economic cost. The definition of the energy scenarios and emission scenarios are summarized in Table 1.

In this paper we focus on the development of energy scenarios and emission scenarios for China. The scenarios for other countries are adapted from those developed by IIASA in a project funded by United Nations Environment Programme (UNEP) and World Meteorological Organization (WMO) (Shindell et al., 2012; UNEP and WMO, 2011). Both the energy consumption and air pollutant emissions were calculated with a five-year time step, although the parameters and results are presented for selected years only. Detailed assumptions of the energy scenarios and emission scenarios are documented below.

3.1 Development of energy scenarios

For countries other than China, our BAU and PC scenarios are consistent with the energy pathways of the reference and 450 ppm scenarios in Shindell et al. (2012) and in UNEP and WMO (2011), which were based on the reference and 450 ppm scenarios presented in the World Energy Outlook 2009 (IEA, 2009), respectively. While the reference scenario is based on current energy and climate-related policies, the 450 ppm scenario explores the global energy consumption if countries take coordinated action to restrict the global temperature increase to 2 °C. The details of energy scenarios are described in Shindell et al. (2012), UNEP and WMO (2011) and IEA (2009).

For China, we have developed two energy scenarios that are consistent with our previous paper (Zhao et al., 2013c). Presented below is a brief description of the assumptions and results of the energy scenarios; see Zhao et al. (2013c) for detailed information. Note that because that paper focused on the emission trends of NO_x, it did not project activity data in terms of fossil fuel distribution (included in the industrial sector for this study) nor the use of solvents. These two projections are incorporated below.

We assume that the annual average GDP growth rate will decrease gradually from 8.0 % during 2011–2015 to 5.5 % during 2026–2030. The national population is projected to increase from 1.34 billion in 2010 to 1.44 billion in 2020 and 1.47 billion in 2030, and the urbanization rate (proportion of people in urban areas) is assumed to increase from 49.95 % in 2010 to 58 and 63 % in 2020 and 2030, respectively.

The total electricity production is projected to be 10–12 % lower in the PC scenario than that of the BAU scenario. The PC scenario considers aggressive development plans for clean and renewable energy power generation; therefore, the proportion of electricity production from coal-fired power plants is expected to decrease to 57 % in 2030 in the PC scenario, contrasted with 73 % in the BAU scenario.

We applied an elasticity coefficient method for the estimation of future production of industrial products, the governing equation of which is as follows:

$$Y_{t1} = Y_{t0}\left(\frac{\mathrm{d}v_{t1}}{\mathrm{d}v_{t0}}\right)^{\delta} \quad (1)$$

where, $t0$, $t1$ are time periods, e.g., $t0 = 2010$, and $t1 = 2030$; Y is the yield of a specific industrial product; dv is the driving force, namely sectoral value added or population; and δ is the product-specific elasticity coefficient. The values of δ are determined through (1) historical trends during 1995–2010; (2) the experience of developed countries; and (3) projections of industrial associations. Generally speaking, production of most energy-intensive commodities used in construction of infrastructure are expected to increase until 2020, and then to stabilize or even decline after 2020, whereas products associated with household consumption are expected to increase through 2030, although at a declining rate. We projected lower production of industrial products in the PC scenario than those of the BAU scenario because of more energy-conserving lifestyles. The penetrations of less energy-intensive technologies are assumed to be higher in the PC scenario than the BAU scenario.

For the residential sector, China's building area per capita in the PC scenario is expected to be 3–4 m^2 lower than that of the BAU scenario in both urban and rural areas. The heating energy demand per unit area is somewhat lower in our PC scenario because of the implementation of new energy-conservation standards in the design of buildings. Replacement of coal and direct biomass burning with clean fuels are assumed in both urban and rural areas, with faster progress in the PC scenario.

The vehicle population per 1000 persons is projected at 380 and 325 in the BAU and PC scenarios, respectively. The PC scenario also assumes aggressive promotion of electric vehicles, and a progressive implementation of new fuel efficiency standards, resulting in 33 and 57 % improvement in the fuel economy of new passenger cars and new heavy-duty vehicles by 2030.

The increase of fossil fuels stored and distributed is expected to be consistent with the increase of total fuel consumption in the future. The gasoline or diesel sold at service stations is expected to have the same growth rate as fuel consumption in the transportation sector. Therefore, the activity levels of fossil fuel distribution are derived from the projections of fuel consumption.

The activity data for the solvent use sector are the consumption of products containing solvents. The forecast approach, which is consistent with Wei et al. (2011b), is illustrated as follows:

$$A_{t1} = \sum_j \left(A_{t0,j} \times \frac{Y_{t1,j}}{Y_{t0,j}} \right) \quad (2)$$

where, $t0$, $t1$ are time periods, e.g., $t0 = 2010$, and $t1 = 2030$; j represents the industries using a specific solvent product; A_{t1} is the consumption of this solvent product in the year $t1$; $A_{t0,j}$ is the consumption of this solvent product in industry j in the year $t0$; $Y_{t0,j}$ and $Y_{t1,j}$ are the yields of the major products (e.g., crude steel for the iron and steel industry) for industry j in the year $t0$ and $t1$, respectively. The yields of industrial products were projected using the elasticity coefficient method as described above.

Table 7 shows current and future energy consumption in East Asia. Total energy consumption in East Asia was 123 EJ in 2005 and 161 EJ in 2010. The energy consumption of China accounts for 69–76 % of the total energy amount during 2005–2010, followed by 13–18 % for Japan, and about 7 % for South Korea. By 2030, the total energy consumption is projected to increase to 243 EJ under the BAU scenario and to 195 EJ under the PC scenario, 51 and 21 % higher than that of 2010.

Of all the countries, China is expected to experience the fastest growth rate in energy consumption. By 2030, China's energy consumption is projected to increase by 64 and 27 % from the 2010 level in BAU and PC scenarios, respectively. Industry fuel consumption is expected to increase notably slower than the total fuel use in both scenarios, resulting from the structural economic adjustment. In contrast, the energy consumption of transportation is projected to increase dramatically by 200 and 101 % in the BAU and PC scenarios, respectively, measured in 2030 against the 2010 levels, driven by the swift increase in vehicle population. The growth rate of energy consumption in other sectors is close to that of the total amount. Because of the energy-saving measures, the energy consumption of power plants, industry, residential, and transportation sectors in the PC scenario are 18, 19, 27, and 33 % lower than the BAU scenario, respectively. Coal continues to dominate China's energy mix, but the proportion decreases from 68 % in 2010 to 60 and 52 % in 2030 under the BAU and PC scenarios, respectively. In contrast, the shares of natural gas and "other renewable energy and nuclear energy" are estimated to increase from 3.4 and 7.5 % in 2010 to 5.5 and 8.9 % in 2030 under the BAU scenario, and 9.3 and 15.8 % under the PC scenario, respectively.

By 2030, the energy consumption of East Asia other than China is projected to increase slightly by 12 and 2 % over the 2010 level in the BAU and PC scenarios, respectively. Under current policies, Japan's energy consumption is projected to increase very slightly by 2 % from 2010 to 2030, because of slow economic growth rate and a trend towards higher energy efficiency resulting from current legislation. Under implementation of low-carbon policies intended to limit CO_2 concentrations to 450 ppm, Japan's energy consumption would be reduced by 6 % by 2030 over the 2010 level. This reduction is mainly attributed to the decline in energy consumption of the transportation sector, resulting from improved fuel economy and reduced mileage traveled. By 2030, South Korea's energy consumption is expected to increase by 26 and 15 % over the 2010 level under the two energy scenarios, respectively. Similar to China, there are also evident trends towards clean and renewable energy in Japan and South Korea. For example, from 2010 to 2030, the shares of coal and petroleum products in Japan's energy consumption are expected to decrease from 22 and 40 % to 20 and 31 % under the BAU scenario, respectively, and to 12 and 29 % under the PC scenario. In contrast, the proportion of renewable energy would increase from 16 % in 2010 to 23 % and 33 % in 2030 under the BAU and PC scenarios, respectively.

3.2 Development of emission control scenarios

For the countries other than China, our control strategies [0] and [2] are consistent with the control strategies of the reference scenario and the maximum feasible reduction scenario in UNEP and WMO (2011), respectively. While control strategy [1] assumes that new pollution control policies would be implemented progressively in China, it has the same assumptions as control strategy [0] for the other countries for the following reasons: (1) China accounts for 88, 94, 94, 95, and 88 % of the total NO_x, SO_2, PM_{10}, $PM_{2.5}$, and NMVOC emissions in East Asia in 2010; (2) Japan and South Korea already have stringent environmental policies in the base year, and the progressive control strategy for countries other than China will have negligible effect on the regional outcomes. The major assumptions underlying control strategies [0] and [2] are straightforward: [0] assumes current regulations and implementation status, while [2] assumes full application of best available technologies in the world. Therefore, in the following text, we will focus on the assumptions for China and omit details for other countries. The penetrations of major control technologies in China, Japan, and South Korea are summarized in Table 2 through Table 5.

3.2.1 Power plants

As documented in Sect. 2.2.1, the recently released 12th Five-Year Plan set specific targets and proposed detailed technological roadmaps for the reduction of SO_2 and NO_x emissions from power plants. The government did not set a total PM emission target, but rather a strict in-stack PM concentration standard in 2011 ($30\,mg\,m^{-3}$ for the entire country except for $20\,mg\,m^{-3}$ in key regions, as defined in Sect. 2.2.2). Power plants burning coal with low ash content could attain the $30\,mg\,m^{-3}$ threshold by installing ESP and wet-FGD simultaneously. For units burning coal with high ash content, or when the $20\,mg\,m^{-3}$ threshold applies, HEDs (including FF and electrostatic-fabric integrated precipitators) would be the only commercially available control technology.

The BAU[0]/PC[0] scenarios consider only the control policies released before the end of 2010. In other words, NO_x and PM emissions are mainly controlled with LNB and ESP, respectively. The penetration of FGD would increase quite slowly. The BAU[1]/PC[1] scenarios are based on the 12th Five-Year Plan (including the 2011 emission standards for 2011–2015) and the assumption that high-efficiency control technologies will continue to spread gradually after 2015. The penetration of FGD in coal-fired units is assumed to approach 100 % by 2015. All newly built thermal power plants will be equipped with low-NO_x combustion technologies and flue gas denitrification (SCR or SNCR) from 2011 onwards. Existing thermal power plants will be upgraded with low-NO_x combustion technologies, and large units (≥ 300 MW) will be upgraded with SCR or SNCR during 2011–2015. Selective catalytic reduction and SNCR will gradually spread to smaller units after 2015. More ambitious measures will be required in the key regions. For PM, HED will spread much more rapidly, with its share in coal-fired units approaching 35 and 50 % in 2020 and 2030, respectively. In the BAU[2]/PC[2] scenarios, the best available technologies (i.e., FGD for SO_2, LNB+SCR for NO_x, and HED for PM) are assumed to be fully applied by 2030. Table 2 gives the national average penetration of control technologies. Note that the penetrations in the key regions are usually larger than those of other regions.

3.2.2 Industrial sector

The latest national emission standards for industrial boilers were released in 2001 (GB13271-2001), although several provinces including Beijing and Guangdong have recently issued local standards. As the BAU[0]/PC[0] scenarios are based only on current regulations, i.e., nearly no measures implemented for controlling SO_2 and NO_x emissions, and WET remains dominant control technology for PM emissions. The BAU[1]/PC[1] scenarios are based on the 12th Five-Year Plan during 2011–2015; progressive control measures would be enforced after 2015 as an extension of the 12th Five-Year Plan. For SO_2, FGD systems are assumed to be widely deployed, penetrating 20, 40, and 80 % of the total capacity by 2015, 2020, and 2030, respectively. For NO_x, LNB will be required at newly built industrial boilers, and existing boilers in the key regions will begin to be retrofitted with LNB during 2011–2015. The vast majority of existing boilers are expected to be equipped with LNB by 2020. For PM, ESP and HED will be gradually deployed to replace the less efficient WET. In the BAU[2]/PC[2] scenarios, the most efficient removal technologies, including FGD, LNB+SCR, and HED, will be fully applied.

The emissions from industry processes (i.e., other than boilers) were mainly regulated by the Emission Standard for Industrial Kilns and Furnaces before 2010. Standards for specific industries were only issued for cement plants (GB4915-2004) and coke ovens (GB16171-1996). However, new emission standards for a variety of industries were rapidly issued during 2010–2012, which may significantly alter their future emission pathways.

A series of new emission standards for the iron and steel industry was released in 2012, including the standards for sintering, iron production, steel production, steel rolling, and other processes. Sintering is the main source of SO_2 and NO_x emissions in the iron and steel industry, and also an important source of PM emissions. Installation of wet-FGD is required in order to attain the SO_2 concentration standard, and the 12th Five-Year Plan also requires large-scale deployment of FGD. The threshold for NO_x concentration can be attained without additional control technologies, but the 12th Five-Year Plan requires newly built sintering facilities to be equipped with SCR or SNCR. Most sintering plants can meet the PM threshold with simultaneous installation of FGD and ESP, but HED is required for those in key regions and those with poor raw material quality. The BAU[0]/PC[0] scenarios assume only the continuation of the control regulations as of 2010. The BAU[1]/PC[1] scenarios are developed on the basis of the 2012 standard and the 12th Five-Year Plan. Flue gas desulfurization would be installed at most sintering facilities, and SCR or SNCR at newly built ones during 2011–2015; the penetrations would increase gradually afterwards. While ESP remains the dominant PM-removal technology, it is assumed that HED will be deployed gradually. Flue gas desulfurization, SCR, and HED would be fully applied in the BAU[2]/PC[2] scenarios. Blast furnaces (for pig iron production) in China are usually equipped with washing towers and double venturi scrubbers, which currently remain the best available technologies. The 2012 emission standards for steel production (with basic oxygen furnaces and electric arc furnaces being the major technologies) imply that low efficiency WET should be phased out, and HED needs to be installed for newly built facilities. While the BAU[0]/PC[0] scenarios assume emission standards from before 2010, the BAU[1]/PC[1] scenarios assume the retirement of WET and gradual promotion of HED, according to the 2012 emission standard. The BAU[2]/PC[2] scenarios assume full utilization of HED.

Current emission standards for the cement industry were released in 2004. The SO_2 and NO_x standards can be met without additional control measures, and the PM standard can be met with both ESP and HED. Therefore, we assume the control technology mix of 2010 would remain the same as in the BAU[0]/PC[0] scenarios. In 2012, MEP published new draft of emission standards for public comment. As a cement clinker can absorb most SO_2 produced due to its basic chemistry, even the strengthened SO_2 limit may be attained under favorable technical conditions. The attainment of the NO_x limit requires upgrading with low-NO_x combustion technology for existing kilns (or installation of SNCR as an alternative), and simultaneous utilization of low-NO_x combustion technology and SCR/SNCR for new kilns. The BAU[1]/PC[1] scenarios are based on the 2012 draft standard and the 12th Five-Year Plan. Newly built precalciner kilns (mostly $\geq 4000\,t\,d^{-1}$) are required to be equipped with SCR/SNCR, and existing precalciner kilns should be retrofitted with low-NO_x combustion technology during 2011–2015. Selective catalytic reduction/SNCR are assumed to continue to spread gradually after 2015. HED would be deployed gradually to meet the strengthened PM threshold for new kilns. The BAU[2]/PC[2] scenarios assume full application of desulfurization facilities, LNB+SCR, and HED.

As for coke ovens, we assume no control measures for SO_2 and NO_x emissions, and continuous application of WET for PM emissions in the BAU[0]/PC[0] scenarios. In the BAU[1]/PC[1] scenarios, we assume the installation of FGD in the coal-charging process or coke oven gas exhaust for newly built plants (contributing about 50 and 30 % of emissions, respectively) to meet the requirement of a new standard issued in 2012 (GB16171-2012). In addition, new plants are assumed to be equipped with HED, also required by the new standard. The BAU[2]/PC[2] scenarios assume full application of the best desulfurization, denitrification, and PM removal facilities available.

As for glass production, the BAU[0]/PC[0] scenarios assume no control measures for SO_2 and NO_x emissions, and the current mix of PM removal technologies. The BAU[1]/PC[1] scenarios are designed according to the new emission standards released in 2011, though they are enforced leniently because of difficulty in implementation. Flue gas desulfurization, as well as end-of-pipe NO_x control technologies (typically oxy-fuel combustion technology (OXFL) or SCR), would be applied gradually at both existing and new plants. Outdated PM removal technologies, e.g., WET, would be phased out. For the brick industry, emissions from about 30 % of plants remain uncontrolled in 2010. In 2009 a draft of new emission standards call for a PM removal efficiency of over 60 % at existing plants, and over 80 % at new plants. In the BAU[1]/PC[1] scenarios, PM emissions from brick plants are assumed to be controlled according to the standard, though enforced leniently due to inspection difficulty.

To attain the new emission standards for the nitric acid industry (GB26131-2010), the dual-pressure process would be equipped with absorption technologies (ABSP) or SCR, while other processes need to adopt both ABSP and SCR. The BAU[0]/PC[0], BAU[1]/PC[1] and BAU[2]/PC[2] scenarios assume the technology mix of 2010, lenient enforcement of the new standard, and stringent enforcement of the new standard, respectively.

In the BAU[0]/PC[0] scenarios, we assume the emission standards for gasoline distribution (GB20950, GB20951, and GB20952) would continue to be enforced in the future. In the BAU[1]/PC[1] scenarios, the enforcement of Stage IA, Stage IB, and Stage II controls would be extended to all of China, and IFC would be applied for both newly built and existing storage tanks. In addition, similar control technologies would be applied for crude oil distribution. As a result, the application rate of IFC, Stage IA, and Stage IB+Stage II control measures in gasoline storage and distribution would approach 75 and 100 % by 2020 and 2030, respectively. The application rate in crude oil distribution would be 25 and 50 % by 2020 and 2030, respectively (see Table 4). For the BAU[2]/PC[2] scenarios, these control measures would be fully applied by 2030.

For other industries with NMVOC emissions, nearly no control measures are assumed for the BAU[0]/PC[0] scenarios. In the BAU[1]/PC[1] scenarios, we assume that new NMVOC emission standards (similar to or slightly less stringent than the EU Directives 1999/13/EC and 2004/42/EC, depending on specific industry) will be released and implemented in key regions as of 2015, and in other provinces as of 2020. Afterwards, the emission standards will become more stringent gradually (see Table 4). In terms of technologies, we assume application of basic management techniques (e.g., leakage detection and repair for refineries and improved solvent management in paint production) where they are applicable. End-of-pipe controls (condensation, adsorption, absorption, and incineration) are adopted when high removal rate is required. The penetration of selected control measures assumed for key sources are summarized in Table 4.

3.2.3 Residential sector

Emission control policies have seldom been proposed for the residential sector in China. In the BAU[0]/PC[0] scenarios, we assume no control measures except for the continued application of CYC and WET for residential boilers. In BAU[1]/PC[1], HED and low-sulfur-derived coal are assumed to be deployed gradually, both penetrating 20 and 40 % of the total capacity by 2020 and 2030, respectively. In addition, we assume gradual adoption of advanced coal stoves and advanced biomass stoves (e.g., those with more efficient combustion or catalytic devices) where applicable, which reduce emissions of PM and NMVOC. The BAU[2]/PC[2] scenarios assume the application of best available technology without considering economic cost.

3.2.4 Transportation sector

In the BAU[0]/PC[0] scenarios, only the existing standards (released before the end of 2010) are considered. In the BAU[1]/PC[1] scenarios, all of the current standards in Europe are assumed to be implemented in China gradually, and the time intervals between the releases of standard stages would be a little shorter than those of Europe. The implementation timeline of the emission standards is given in Fig. 1. The removal efficiencies of the future emission standards are from the GAINS-Asia model of IIASA (Amann et al., 2008, 2011). The BAU[2]/PC[2] scenarios assume the same implementation timeline for new standards as the BAU[1]/PC[1] scenario. In addition, old vehicles with high emissions are phased out at a faster pace through compulsory measures and economic subsidies. The proportions of vehicles subject to different emission standards are summarized in Table 5.

3.2.5 Solvent use and open biomass burning

For emissions from solvent use, the BAU[0]/PC[0] scenarios consider only several national standards limiting the NMVOC content of some solvent products (see Sect. 2.2.5). Major assumptions for the BAU[1]/PC[1] scenarios are consistent with the NMVOC emission sources in the industrial sector, i.e., implementation of the EU Directives 1999/13/EC and 2004/42/EC as of 2015–2020, followed by gradually strengthened regulations afterwards. Potential mitigation measures to attain the European standards differ greatly for different emissions sources because of various spraying technologies and chemical properties of the solvent used. However, similar to the industrial sources, these measures can be categorized into two kinds: use of environmentally friendly substitutes (e.g., water-based or UV products) or end-of-pipe control technologies. Substitution measures are assumed where applicable, while end-of-pipe control technologies would be mainly installed in newly built factories. The penetration of selected control measures assumed for key sources are summarized in Table 6.

We assume a ban of open biomass burning in the BAU[2]/PC[2] scenarios.

3.3 Future emission trends and effects of control measures

The air pollutant emissions in each scenario are estimated based on the assumptions in Sects. 3.1 and Sect. 3.2. Table 8 shows the national air pollutant emissions in East Asia under each scenario. Figure 2 shows the emissions by sector in China, and Fig. 3 shows the emissions by sector in Japan and South Korea. Supplement Table S4 shows the provincial emissions in China.

3.3.1 NO_x

Under current regulations and implementation status (the BAU[0] scenario), NO_x emissions in East Asia are projected to increase by 28 % in 2030 from the 2010 levels. The implementation of assumed energy-saving measures (reflected by the difference between the BAU[0] and the PC[0] scenarios) and progressive end-of-pipe control measures (reflected by the difference between the PC[0] and the PC[1] scenarios) are expected to reduce NO_x emissions by 28 and 36 %, respectively, from the baseline projection (the BAU[0] scenario). With the full enforcement of technically feasible control measures (the PC[2] scenario), the remaining emissions account for only 21 % of the baseline projection, or 27 % of the 2010 levels.

China's emission growth potential under current regulations (36 %) is significantly larger than the average of East Asia (28 %), resulting from a great increase in energy consumption and weak existing control measures. China's share in East Asia's NO_x emissions would increase to 93 % under the baseline projection. The enforcement of energy-saving measures (the PC[0] scenario) leads to a 29 % reduction from the baseline projection. With the implementation of the 12th Five-Year Plan and slowly strengthened end-of-pipe control policies after 2015 (reflected by the difference between the PC[0] and the PC[1] scenarios), China's NO_x emissions could be reduced by nearly 40 % (compared to the baseline projection). The most effective control measures are the installation of SCR and SNCR and the application of stringent vehicle standards, which together achieve nearly 80 % of this reduction. The full application of technically feasible control measures (the PC[2] scenario) could reduce China's NO_x emissions to 20 % of the baseline projection, or 28 % of the 2010 levels. It should be noted that the NO_x emissions are projected at 22.9 Mt in 2015 under the BAU[1] scenario, 12.2 % lower than that of 2010. This implies that if the control policies in the 12th Five-Year Plan can be implemented successfully (as assumed in the BAU[1] scenario), the national target to reduce the NO_x emissions by 10 % during 2011–2015 would be achieved.

Under current regulations and implementation status, the NO_x emissions in East Asia other than China are expected to decrease by 27 %, with especially rapid decline in Japan (47 %) and South Korea (34 %). The decrease is mainly attributable to the continuously increasing proportion of vehicles subject to stringent emission standards. With the enforcement of energy-saving policies intended to limit global temperature increase to 2 °C (reflected by the difference between the BAU[0] and the PC[0] scenarios), NO_x emissions in East Asia outside of China, and of the two major energy consumers therein (Japan and South Korea), are all expected to decline by 15–17 % in 2030 compared with the baseline projection. These policies are most effective in the power sector, due to negligible emissions from renewable and nuclear power generation compared with traditional coal-fired power. The full application of technically feasible control measures (the PC[2] scenario) would reduce the NO_x emissions in East Asia except China, and Japan and South Korea individually to only 30, 46 and 30 % of the baseline projection, or 22, 24 and 20 % of the 2010 levels, respectively.

3.3.2 SO_2

The SO_2 emissions in East Asia are predicted to grow 24 % from 2010 to 2030 under current regulations and implementation status (the BAU[0] scenario). The enforcement of advanced energy-saving measures (the PC[0] scenario) could lead to a substantial 36 % reduction in SO_2 emissions from the baseline projection, exceeding the effect of progressively implemented end-of-pipe control measures, 25 % (reflected by the difference between the PC[0] and the PC[1] scenarios). Flue gas desulfurization facilities had been intensively deployed by 2010 in most industrial sources of Japan and in the power plants of China and South Korea. Therefore, the reduction potential through the installation of end-of-pipe control technologies will likely decline in the future, spotlighting the importance of energy-saving measures for further reduction of SO_2 emissions. With the full application of best available technologies (the PC[2] scenario), the remaining SO_2 emissions in East Asia would account for only 27 % of the baseline projection, or 34 % of the 2010 levels.

Similar to NO_x, China's SO_2 emissions have a larger growth potential than the average of East Asia during 2010–2030 under the current policy and implementation status. Implementation of new energy-saving measures (reflected by the difference between the BAU[0] and the PC[0] scenarios) and progressive end-of-pipe control measures (reflected by the difference between the PC[0] and the PC[1] scenarios) could lead to 36 and 26 % reductions of China's SO_2 emissions, respectively (compared with the baseline projection). Consistent with the total emissions in East Asia, the contribution of energy-saving measures clearly exceeds the planned end-of-pipe control policies. As the power sector had largely been equipped with FGD facilities by the base year, industrial boilers and industrial process contribute 82 % of the SO_2 emission reduction achieved through progressive end-of-pipe control policies. Assuming the full enforcement of technically feasible control measures (PC[2]), SO_2 emissions are estimated to reach only 27 % of the baseline projection, or 34 % of the 2010 levels.

We also note that China's SO_2 emissions are projected to be 21.7 Mt in 2015 under the BAU[1] scenario, 11.1 % lower than those of 2010. This implies that if the control policies in the 12th Five-Year Plan could be implemented successfully (as assumed in the BAU[1] scenario), the national target to reduce the SO_2 emissions by 8 % during 2011–2015 would be achieved.

The SO_2 emissions in East Asia outside of China, including Japan and South Korea individually, are expected to stay relatively stable until 2030 under current regulations. The implementation of new energy-saving polices (the PC[0] scenario) could lead to a 9–18 % reduction in SO_2 emissions from the levels of the baseline projection. The reduction is mainly achieved thorough the promotion of nuclear and renewable power generation and replacement with cleaner fuels in the industrial sector. Under the full application of technically feasible reduction measures (the PC[2] scenario), the SO_2 emissions in East Asia except China, and Japan and South Korea individually would be reduced to 33, 52 and 39 % of the baseline projection, respectively.

3.3.3 PM_{10} and $PM_{2.5}$

PM_{10} and $PM_{2.5}$ emissions in East Asia are projected to remain relatively stable up until 2030 under the current policies (the BAU[0] scenario), resulting from growth in energy consumption offset by reduction from existing control policies (in particular, vehicle emission standards). New energy-saving policies (reflected by the difference between the BAU[0] and the PC[0] scenarios) and progressive end-of-pipe control measures (reflected by the difference between the PC[0] and the PC[1] scenarios) result in about 28 and 23 % reduction in PM_{10} and $PM_{2.5}$ emissions from the levels of baseline projection, respectively. Full application of best available technologies (the PC[2] scenario) could reduce PM_{10} and $PM_{2.5}$ emissions to about one-quarter of the levels of the baseline projection or the base year.

China's future PM_{10} and $PM_{2.5}$ emission trends under the studied scenarios are quite similar to those of East Asia as a whole. Similar to SO_2, the effects of advanced energy-saving polices (resulting in about 29 % reduction of $PM_{2.5}$ emissions from the baseline projection) exceeds the planned end-of-pipe control measures (about a 25 % reduction). With the energy-saving measures applied, the reduction in emissions from the residential sector is especially pronounced (nearly 60 %), resulting from the replacement of coal and biomass with cleaner fuel types. The most effective end-of-pipe control policies are the application of recently released new emission standards for various industrial sources. We estimate that these new industrial standards lead to over 20 % reduction of China's total PM_{10} and $PM_{2.5}$ emissions. If the best available technologies are fully applied (the PC[2] scenario), the PM_{10} and $PM_{2.5}$ emissions would be reduced to about one-quarter of the levels of baseline projection or the levels of the base year.

The total PM_{10} and $PM_{2.5}$ emissions in East Asia other than China are also expected to remain relatively stable up until 2030 under the current policies. An exception is Japan, whose PM_{10} and $PM_{2.5}$ emissions are projected to decrease about one-quarter by 2030. The major driving force underlying this decline would be an increasing proportion of vehicles regulated by newer emission standards. The implementation of new energy-saving policies (the PC[0] scenario) is expected to reduce the $PM_{2.5}$ emissions of East Asia other than China, and Japan and South Korea individually by about 20, 17, and 5 %, respectively, from the baseline projection. With full application of best available control technologies (the PC[2] scenario), the $PM_{2.5}$ emissions in East Asia except China, and Japan and South Korea individually would account for about one-quarter, one-half, and one-half of the levels of the baseline projection, respectively.

3.3.4 NMVOC

Under current regulations and implementation status (the BAU[0] scenario), NMVOC emissions in East Asia are projected to increase by 24 % by 2030 from the 2010 levels. The implementation of assumed energy-saving measures (reflected by the difference between the BAU[0] and the PC[0] scenarios) and progressive end-of-pipe control measures (reflected by the difference between the PC[0] and the PC[1] scenarios) are expected to reduce NMVOC emissions by 15 and 23 %, respectively, from the baseline projection. Up to 62 % of the total NMVOC emissions are expected to remain even with the assumed energy-saving measures and progressive end-of-pipe controls enforced together. There remains large potential to reduce NMVOC emissions beyond the progressive control strategies, since the full application of best available technologies (the PC[2] scenario) could reduce NMVOC emissions to only 35 % of the baseline projection.

China's NMVOC emissions are estimated to increase by 27 % from 2010 to 2030 under the current policy and implementation status. This upward trend is stronger than the East Asia average but weaker than China's NO_x emissions. The emissions from the transportation and residential sectors are expected to decline as a result of existing emission standards for vehicles and the dwindling direct combustion of biomass in the residential sector. By carrying out a series of energy-saving policies (the PC[0] scenario), total emissions are expected to decrease by 16 % from the baseline projection. Emissions from the residential sector decrease most notably because of the substitution of biomass with cleaner fuels. Another 26 % could be reduced if progressive end-of-pipe control measures are implemented (reflected by the difference between the PC[0] and the PC[1] scenarios), and the most effective measures are the substitution with low-solvent products and end-of-pipe removal technologies such as incineration and adsorption in the industrial sector and the use of solvents. With full implementation of the best available technologies (the PC[2] scenario), the NMVOC emissions could be reduced to about one-third of the levels of the baseline scenario.

The NMVOC emissions in East Asia outside of China are expected to increase by 5 % from 2010 to 2030 under current regulations. The growth rates in Japan and South Korea are 4 and 9 %, respectively. This slight upward trend is an integrated effect of the reduction in transportation emissions due to increased share of low emission vehicles, and the increase of emissions from solvent use due to inadequate control policies. By 2030, solvent use contributes about 80 % of total NMVOC emissions in both Japan and Korea under the baseline projection. As solvent use has little to do with fuel consumption, the implementation of energy-saving policies has very limited effects on the reduction of NMVOC emissions. In contrast, the full application of end-of-pipe control measures (the PC[2] scenario) would reduce the emissions from solvent use dramatically, to about one-quarter of the baseline projection.